

## Design Analysis of Two Wheeler Lighter Weight Alloy Wheel

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## ABSTRACT

In many areas of industry, it is desirable to create geometric models of existing objects for which no such model is available. This paper explores the designing of new better lighter alloy wheel similar to the existing design through the reverse engineering process. After the process of duplicating an existing component by capturing the components physical dimensions. Simulating the alloy wheel models of new and existing models with respect to static and fatigue analysis for finding the von misses stress and fatigue life of the models. Presenting the most important modeling, construction steps and various loading strategies are outlined. To promote the scientific understanding of Mg-alloy & Al-alloy materials for motorcycle (Li-hong et al. 2009) alloy wheel under same service conditions mentioning Pros and cons of them. For better change in design project reducing number of spokes in presently existing spokes for weight and reduced stresses. A typical alloy wheel configuration of Suzuki GS150R commercial vehicle is chosen for study. Finite element analysis has been carried out to determine the safe stresses and pay loads. The present work attempts to analyse the safe load of the alloy wheel, which will indicate the safe drive is possible.

**Keywords:** CAD, geometric modelling, reverse engineering, Motorcycle, Geometric modeling and Designing, Rim, Alloy-spokes, Al & MAG wheels, Lightweight & Anti-fatigue design.

## Abbreviations:

|       |                                           |
|-------|-------------------------------------------|
| CAD - | Computer Aided Design                     |
| PTC-  | Parametric Technology Corporation         |
| CAM-  | Computer Aided Manufacturing              |
| CAE-  | Computer Aided Engineering                |
| 3D-   | Three Dimensional                         |
| 2D-   | Two Dimensional                           |
| GUI-  | Graphical User Interface                  |
| IGES- | Initial Graphics Exchange Specification   |
| ASTM- | American Society of Testing and Materials |
| FEA-  | Finite element analysis                   |
| CRT-  | Cathode-ray tube                          |
| RSPM- | Rapid solidification powder metallurgy    |
| HCF-  | High cycle fatigue                        |

## How to cite this article

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# 1. INTRODUCTION

## 1.1. History

Components which are manufactured from cast alloys have been widely utilized in automotive industry, due to its high strength to weight ratio, low cost and better fuel consumption. With the increasing usage of aluminum alloy, reliability requirements for aluminum components have become more critical. In recent years, aluminum wheels (Angmo Wang et al. 2009) have been significantly used in transport vehicles because they are important safety components in vehicle suspension systems that support static and dynamic loads encountered during vehicle operation. Automotive wheels have complicated geometry and must satisfy manifold design criteria, such as style, weight, manufacturability, and performance. In addition to a fascinating wheel style, wheel design also needs to accomplish a lot of engineering objectives including some necessary performance and durability requirements. Moreover, in order to ensure driving comfort and road handling characteristics, the wheel must be as light as possible. Now days, reduction in wheel weight is a major concern in wheel industry. For wheel manufacturers, reduction in wheel weight means a reduction in material cost. In order to reduce the manufacturing cost, wheel weight must be minimized, while wheel must still have enough mechanical performance to suffer normal or severe driving conditions. Traditionally, wheel design and development is very time consuming, because it needs a number of tests and design iterations before going into production. In modern industry, how to shorten development time and to reduce the number of times of test are important issues. In order to achieve the above objectives, computer aided engineering (CAE) is a useful tool and has been recently carried out to perform a wheel design. Recently the procedures have significantly improved with the emergence of innovative method on experimental and analytical analysis. Lighter wheels can improve handling by reducing unsprung mass, allowing suspension to follow the terrain more closely and thus improve grip, however not all alloy wheels are lighter than their steel equivalents. Reduction in overall vehicle mass can also help to reduce fuel consumption.

## 1.2. Objective

To create cad model of pre-existing alloy wheel through *reverse engineering process* and doing simulation on new and existing alloy wheel designs that focus on reducing the mass of the current design and selecting better wheel material. The new designs include reducing the number of spokes, modifying the fillet radius at the intersection of the spoke and the hub.

## 1.3. Literature Survey

Reverse engineering is the process of discovering the technological principles of a device, object or system through analysis of its structure, function and operation. It often involves taking something (e.g., a mechanical device, electronic component, biological, chemical or organic matter or software program) apart and analysing its workings in detail to be used in maintenance, or to try to make a new device or program that does the same thing without using or simply duplicating (without understanding) the original(re). Reverse engineering has its origins in the analysis of hardware for commercial or military advantage. The purpose is to deduce design decisions from end products with little or no additional knowledge about the procedures involved in the original production. The same techniques are subsequently being researched for application to legacy software systems, not for industrial or defence ends, but rather to replace incorrect, incomplete, or otherwise unavailable documentation. Reverse engineering can even help companies improve on equipment designs by allowing engineers to develop 3D CAD drawings that they can manipulate and redesign in order to produce new molds, models or parts. These future engineers are onto something. Taking a complex machine apart is one of the best ways to discover how it operates and to recreate that functionality. This concert is called "reverse engineering". Another way to understand reverse engineering it to think of it as deconstructing a machine to discover what's inside and how all the pieces fits together to create the whole. Any company that relies on expensive mechanical equipment can benefit from arming their engineers with reverse engineering software, including businesses in the consumer products, automotive, aerospace, medical, military, manufacturing, assemblies, education, film production and packaging industries (William B Thompson, 1999).

### 1.3.1. Motivation for Reverse Engineering

Interfacing, Military or commercial espionage, Improve documentation shortcomings, Obsolescence, Software Modernization, Product Security Analysis, Bug fixing, Creation of unlicensed/unapproved duplicates, Academic/learning purposes, Competitive technical intelligence

Following are reasons for reverse engineering a part or product:

1. The original manufacturer of a product no longer produces a product
2. There is inadequate documentation of the original design
3. The original manufacturer no longer exists, but a customer needs the product
4. The original design documentation has been lost or never existed
5. Some bad features of a product need to be designed out.
6. To strengthen the good features of a product based on long-term usage of the product
7. To analyze the good and bad features of competitors' product
8. To explore new avenues to improve product performance and features
9. To gain competitive benchmarking methods to understand competitor's products and develop better products
10. The original CAD model is not sufficient to support modifications or current manufacturing methods
11. The original supplier is unable or unwilling to provide additional parts
12. The original equipment manufacturers are either unwilling or unable to supply replacement parts, or demand inflated costs for sole-source parts
13. To update obsolete materials or antiquated manufacturing processes with more current, less-expensive technologies. etc

Finite element analysis (FEA) which can evaluate the mechanical performance of prototypes provides an effective tool for wheel design. In particular, design modification based on the results of FEA can be carried out to investigate how the change would affect its performance, without making costly correction to tooling and equipment in real production (Riesner et al. 1993). Therefore, FEA of wheel testing plays a critical role in wheel design and optimization, which can result in shortening of design time, reduction of wheel weight, enhancement of mechanical performance and lower cost of development. Several studies which were related to the numerical simulation of wheel loading test have been reported in the literature, as described below. In an early study, Riesner et al (1993) purposed the application of FEA to the structural analysis of aluminium wheels in simulating the wheel test. Russo used a nonlinear dynamic FEA approach to simulate the wheel impact behaviour. In this regard, a simplified model of the wheel could be used to simulate the dynamic impact test and generate acceptable results for wheel design purpose.

#### 1.4. Purpose and Scope

A wheel rim is a highly stressed component in an automobile that is subjected to loads. Because of the long life and high stresses, as well as the need for weight reduction, material and manufacturing process selection is important in rim design. There are competitions among materials and manufacturing processes, due to cost performance, and weight. This is a direct result of industry demand for components that are lighter, to increase efficiency, and cheaper to produce, while at the same time maintaining fatigue strength and other functional requirements (Lawrence et al. 1988).

Alloy wheels which are used in motor cycles should essentially pass several types of tests before selling in the market, such as dynamic cornering fatigue test, dynamic radial fatigue test, and static loading test etc. However, it takes a lot of time to produce samples for testing in the design stage of wheel development. Therefore, in order to reduce the time and cost needed for completing a wheel design and to fabricate a wheel with required performance, employment of finite element analysis (FEA) is necessary for a success in design and production of a light-weight and high-quality wheel. In modern wheel industry, FEA have been extensively used in simulation of the wheel tests to evaluate the mechanical performance of alloy wheels. So far, FEA of the dynamic cornering and radial fatigue tests could well predict the fatigue life that a wheel can survive and have exhibited good correlation with the practical testing results. Nevertheless, FEA modeling of the generally used 13-degree impact test still did not have sufficient accuracy and is difficult to accurately predict the locations that failure may take place during impact test. Moreover, to date, there has been little empirical research conducted on the numerical simulation of the 13-degree wheel impact testing. In this regard, it is important to evaluate the effect of the rim portion on wheel performance testing. The main purpose of the current study is, by using a commercial FEA code (solid works), to investigate the effect of the rim portion on the performance of alloy wheels and to design the better model than existing one. A 3-D FEA model of alloy wheel studied in the present work was constructed on the basis of a wheel design developed at alloy wheel manufacturer through reverse engineering process. Such results will help predict the locations that failure may take place during wheel simulation and improve the design of a wheel with required mechanical performance.

A paper published in the year 2009, which is about the fatigue analysis of aluminium wheel rim by Liangmo Wang - Yufa Chen - Chenzhi Wang - Qingzheng Wang School of Mechanical Engineering, Nanjing University of Science & Technology, China. To improve the quality of aluminum wheels, a new method for evaluating the fatigue life of aluminum wheels is proposed in that paper. The ABAQUS software was used to build the static load finite element model of aluminum wheels for rotary fatigue test. Using the method proposed in this paper, the wheel life cycle was improved to over  $1.0 \times 10^5$  and satisfied the design requirement. The results indicated that the proposed method of integrating finite element analysis and nominal stress method was a good and efficient method to predict the fatigue life of aluminum wheels. In this paper, for predicting the wheel fatigue life, the nominal stress method was integrated into the CAD / CAE technology to simulate the rotary fatigue test.

#### 1.5. Static analysis

The wheel was constrained around flange edge of the rim and loaded with a constant force at the end of the shaft, see Fig. The load shaft and wheel were connected by bolts. Due to the main concern being wheel deformation, the load shaft in the FEA analysis was defined as a rigid body, using tie connection with wheel. J area under the wheel rim was under full constraints. Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variation calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Top established a broader definition of numerical analysis. The paper centred on the "stiffness and deflection of complex structures".

**N. Satyanarayana & Ch. Sambaiah:** During the part of project a static analysis of aluminum alloy wheel A356 was carried out using FEA package. The 3 dimensional model of the wheel was designed using CATIA. Then the 3-D model was imported into ANSYS using the IGES format. We find out the total deformation, alternative stress and shear stress by using FEA software. And also we find out the life, safety factor and damage of alloy wheel by using S-N curve. S-N curve is input for an A.356.2 material. For a wheel maker, reduction in the development time means a reduction in the cost. Hence, to find an effective way of static analysis which can be equivalent to the same impact effect of dynamic loading is an important issue.

**G HARINATH GOWD:** During the part of project a STATIC ANALYSIS OF LEAF SPRING was carried out using FEA package. The 3-dimensional model of the leaf spring was modelled. Then model was meshed in ANSYS. Analysis found out the total deformation, alternative stress by using FEA software. And also found out the life, safety factor and damage of leaf spring with Material Manganese Silicon Steel.

**WU Li-hong, LONG Si-yuan, and GUAN Shao-kang:** Replacement of A365 with AM60A, service stress distribution in the wheel becomes more uniform, the peak value of the concentrated stress reduced due to low elastic modulus of Mg alloys. The service stress level of redesigned Mg wheel is relaxed further because of its optimized structure by altering the spoke configuration and increasing the fillet between spoke and ring, satisfying the desired reliability with weight saving.

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**MohdZulHazmi Bin MhdFauzy, Ruzanna Nadia and BintiNisah:** During the part of project a static and fatigue analysis of aluminum alloy wheel was carried out using FEA package. The 3 dimensional model of the wheel was designed using CATIA. Then the 3-D model was imported into NASTRAN using the IGES format. We find out the total deformation, alternative stress and shear stress by using FEA software. There are too many tests that must be considered before an alloy wheels are ready to enter the market. For this project, static test were choose to analyse on the design of the alloy wheels.

**MakkienKeng:** In this project presents the new design of cast metal matrix automotive wheel using simulation of low pressure die casting. By using CATIA, a 3-dimensional model of new automotive wheel design is developed as the master pattern. As an approach to simulate the actual casting process, casting simulation tool is used to introduce the cast metal matrix material with composition of aluminum A356 alloy and 20wt% Sic particles into the cast wheel. Then, the finite element model of the wheel is built and solved by using ANSYS.

**MohdIzzatFaliqfarhan Bin Baharom:** For this project, they used reverse engineering approach to study motorcycle rim, spoke. Due to the confidentiality of the product specifications by the manufacturers, we were unable to obtain the specifications from the manufacturers. Therefore, we disassembled the wheel from a motorcycle and measured the specifications with their knowledge on metrology. Design of the automotive alloy wheel using Solid Works software product. Simulation data collected by using FEA software. Stress analysis on alloy wheel is carried out.

**Liangmo Wang - Yufa Chen - Chenzhi Wang:** To improve the quality of aluminum wheels, a new method for evaluating the fatigue life of aluminum wheels is proposed in that paper. The ABAQUS software was used to build the static load finite element model of aluminum wheels for rotary fatigue test. Using the method proposed in this paper, the wheel life cycle was improved to over  $1.0 \times 10^5$  and satisfied the design requirement. The results indicated that the proposed method of integrating finite element analysis and nominal stress method was a good and efficient method to predict the fatigue life of aluminum wheels.

**Wei-Chan Chang:** The main purpose of that study is, by using a commercial FEA code (ABAQUS), to investigate the effect of the tire portion on the impact performance of tested aluminum wheels and to find out an effective way of static analysis which can be equivalent to the same impact effect of dynamic loading. A 3-D FEA model of each wheel studied in the present work was constructed on the basis of a wheel design developed at a local aluminum wheel manufacturer.

## 1.6. The problem with MAG wheels in early days

Magnesium alloy wheels, or mag wheels, are sometimes used on race cars, in place of heavier steel or aluminum wheels, which are heavier than MAG wheels most street vehicles. Note that aluminum wheels are often mistakenly called "mag wheels". Oil consumption reduction and performance enhancement have become the development trend of road vehicles, especially for motorcycles. Due to the nature of high-speed motion and rotation, weight reduction of the wheels is thought of as the most efficient way to reduce the oil consumption, improve the accelerating and braking performance, and enhance the riding comfort of a road vehicle. Naturally, use of lightweight materials on the wheels is the most straightforward way to achieve the goal. So recent developed Magnesium alloys are considered as the most promising metal material in the 21st century, which possesses the attractive properties desired by motorcycles in comparison with steel and Al alloy, such as low density, low cost, higher specific strength, good casting properties, and outstanding damping capability. When used as wheel material, Mg alloys are not only able to reduce the wheel mass and save oil, but also facilitate absorbing vibration and damping the noise emission, enhancing accelerating and braking performance, thus improving the resultant riding comfort. From steel wheel to Al wheel, lightweight Mg alloys have become the first candidate material of wheels. However, the service states of road wheels are complicated due to the influence of the loads during service, like torsion, impact, vibration, and so on. At present, Mg alloy application on motorcycle wheels lacks theoretic guide because structural design for most of the road wheels available on the market are, nevertheless, based on Al alloys. To promote a scientific understanding of the effect of material substitution and structural features of wheel in service, numerical analyses of stress distribution in wheels of both 356 Al alloy and AM60B Mg alloy under the same service condition were carried out, and the AM60B Mg wheel structure was redesigned and optimized with finite element method (Wang Xiaofeng, 2006).

## 1.7. Designing from aluminium to magnesium (Design guide of Magnesium Elektron 2012)

Magnesium is best known for its light weight but it also has some other excellent attributes. Magnesium alloys have excellent strength to weight ratio, good fatigue strength and high damping capacity. Its nonmagnetic, has good thermal and electrical conductivity. Magnesium can be shaped by practically all the known metal working techniques like cast by the sand, investment, permanent mould and die casting, extruded, processed via powder metallurgy technology, can be formed into shapes by forging, drawing, spinning, stamping, impact extrusion and super plastic forming. To further enhance safety, a new generation of wrought and sand casting magnesium alloys has been developed, Eletron 43, 21, and 675, ZK 60 etc. which are inherently flame – resistant even beyond their melting points.

## 1.8. Mg Alloys are well known for the following properties

1. Ultra-lightness
2. Strength
3. Machinability
4. Cast ability
5. EMI/ RF Radiation shielding
6. Low inertia
7. Creep Resistance
8. Formability
9. Dent Resistance

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**Table 1**  
Shows Geometric Properties of alloy wheel

|                    |                                                               |                    |        |
|--------------------|---------------------------------------------------------------|--------------------|--------|
| Hub Diameter       | 145 mm                                                        | Rim thickness      | 6mm    |
| Hub thickness      | 8 mm                                                          | Rim outer diameter | 500 mm |
| Spoke Length       | 155 mm                                                        | Number of spokes   | 6 to 4 |
| Spoke fillet radii | <div>✓ at hub 5R</div> <div>✓ at outer rim 7R &amp; 13R</div> |                    |        |

**Table 2**  
The following are the material properties of the given alloy wheel. Type of model is Linear Elastic Isotropic

| S. No | PROPERTY                          | Al Alloy<br>201.0-T43 Insulated<br>Mold Casting (SS) | Mg Alloy<br>ZK60 <sup>o</sup> |
|-------|-----------------------------------|------------------------------------------------------|-------------------------------|
| 1     | Elastic Modulus(GPa)              | 71                                                   | 45                            |
| 2     | Poisson's Ration                  | 0.33                                                 | 0.35                          |
| 4     | Mass Density (kg/m3)              | 2800                                                 | 1700                          |
| 5     | Tensile Strength (MPa)            | 273                                                  | 425                           |
| 7     | Yield Strength (MPa)              | 225                                                  | 382                           |
| 8     | Thermal Expansion Coefficient(/K) | 1.9e-005                                             | 1.9e-005                      |
| 9     | Thermal Conductivity W/(m. K)     | 121                                                  | 160                           |
| 10    | Specific Heat J/(kg.K)            | 963                                                  | 1000                          |

**Table 3**  
The following are the material properties of the given alloy wheel. Type of model is Linear Elastic Isotropic

|                                      |               |               |               |
|--------------------------------------|---------------|---------------|---------------|
| Mesh type                            | Solid Mesh    |               |               |
| Mesher Used:                         | Standard mesh |               |               |
| Jacobian points                      | 4 Points      |               |               |
| TYPE OF WHEEL MODEL                  | With 6 Spokes | With 5 Spokes | With 4 Spokes |
| Element Size                         | 6 mm          | 6 mm          | 6 mm          |
| Tolerance                            | 0.3 mm        | 0.3 mm        | 0.3 mm        |
| Mesh Quality                         | High          | High          | High          |
| Total Nodes                          | 138283        | 129933        | 121024        |
| Total Elements                       | 77485         | 72121         | 66289         |
| Maximum Aspect Ratio                 | 27.471        | 27.339        | 27.337        |
| % of elements with Aspect Ratio < 3  | 76.2          | 74.2          | 72.8          |
| % of elements with Aspect Ratio > 10 | 0.246         | 0.326         | 0.291         |
| % of distorted elements(Jacobian)    | 0             | 0             | 0             |
| Time to complete mesh*(hh:mm:ss):    | 00:02:00      | 00:01:59      | 00:01:56      |

## 10. Corrosion Resistance

Forged mag wheels are extremely durable and rigid. The strength of a forged wheel made from magnesium alloy exceeds many times the strength of a cast Al disk. This is achieved by forming a unique fiber structure of the alloy manufactured by the precision 3-D hot forging process in a press with a 20,000 ton capacity. A forged wheel does not crack; it bends without cracking and can be easily repaired, if necessary. Common casting defects, such as cavities and cracks, are non-existent in forging. So our forged mag wheels are stronger and more durable. Also, all forged mag wheels produced by SMW Engineering undergo strict quality control to comply with road safety requirements. Forged mag wheels are very lightweight, as much as 1.5 times lighter than aluminum wheels, and 2.2 times lighter than steel wheels. forged magnesium wheels are twice as light compared to cast Al wheels of the same dimensions. Due to lacks of theoretic guide, most of street bike wheels are of Al-alloy. Wheel weight is a key component in "un-sprung" mass of an automobile (tires, wheels, brake disks, etc.), which directly affects vehicle performance parameters and the lifetime of suspension components. A lighter wheel is much easier to spin and to stop due to a lower momentum of inertia. Forged mag wheels yield shorter breaking distance and faster acceleration, improve manoeuvrability and overall performance and safety, and reduce fuel consumption (by up to 5-7%). The dampening ability (the absorption of shocks and vibrations caused by road imperfections) of magnesium alloys is 100 times higher than those made from aluminum and 23 times higher than steel. This promotes increased durability of suspension brackets, smooth and easy motion of the car, and a longer lifetime of the suspension and brakes. The high heat conductivity property of magnesium also means cooler brake disks and brake drums and a longer life for brake pads.

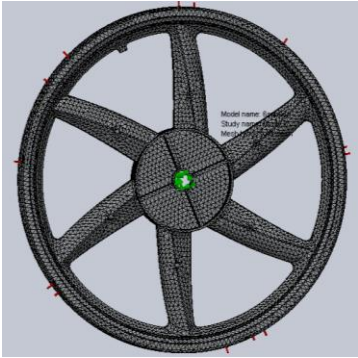
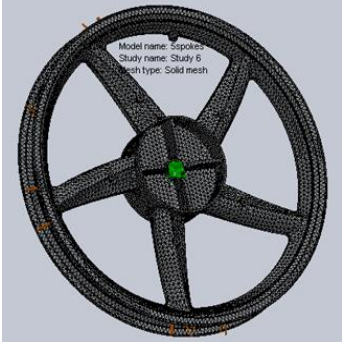
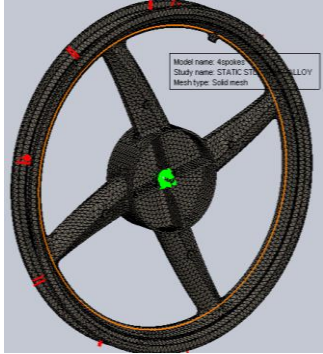
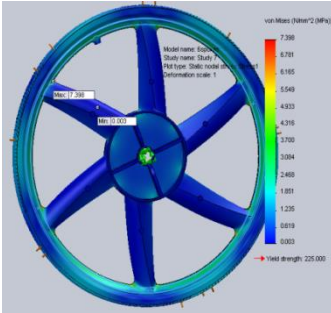
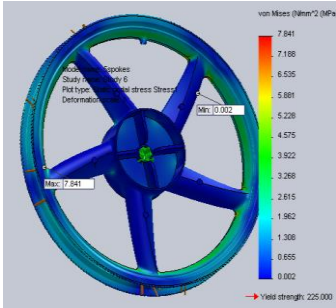
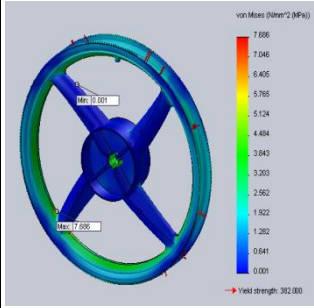
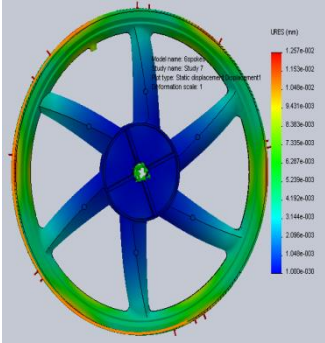
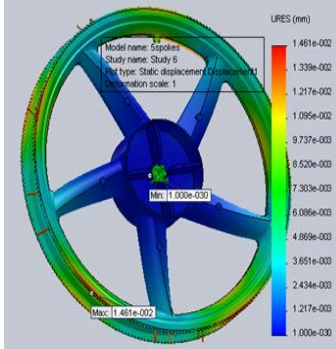
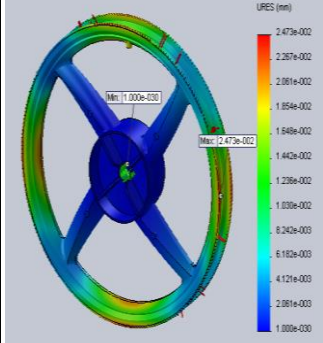
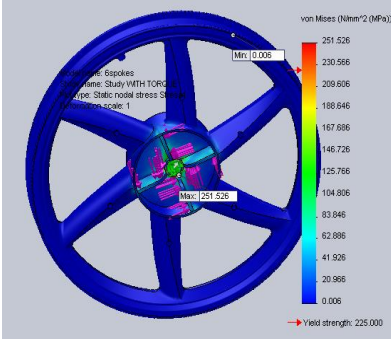
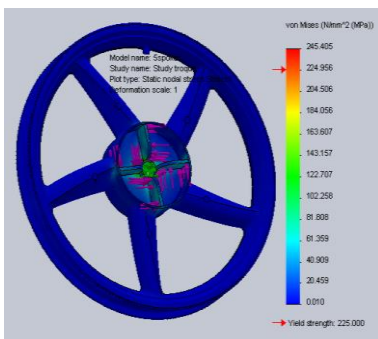
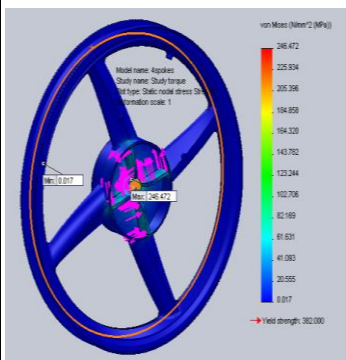
## 1.9. Modulus of Elasticity

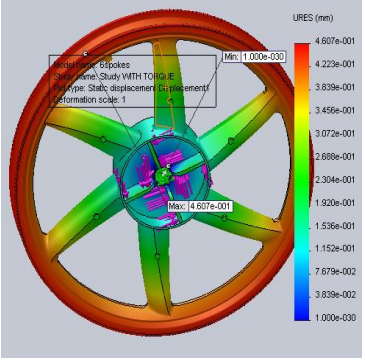
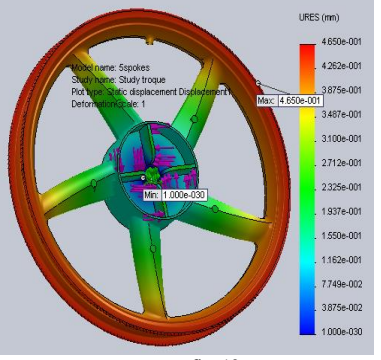
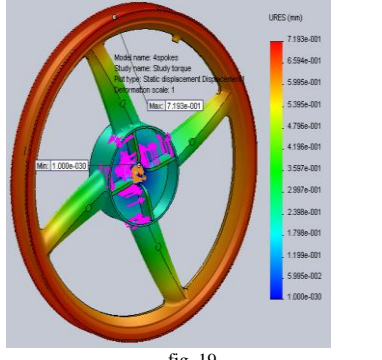
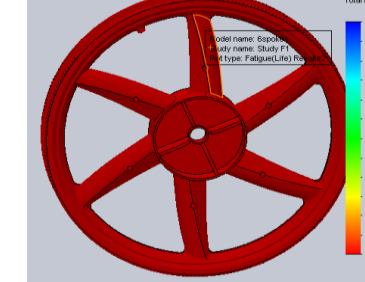
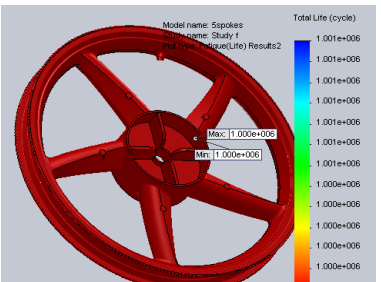
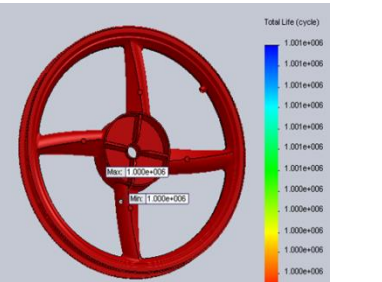

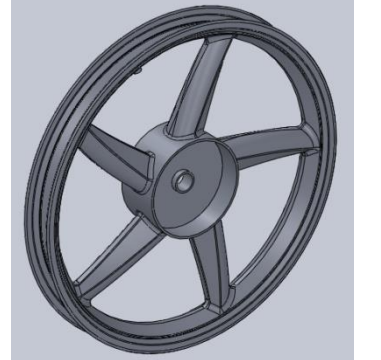

The young's modulus of magnesium alloy is about 44 GPa as compared with 70GPa for aluminium alloys and 207 GPa for mild steel. The modulus generally reduces with increasing temperature but is only slight affected by alloy condition and composition. For given strain it is necessary to proportionally stiffen magnesium components as compared with those made from alloys with higher modulus (e.g. aluminium), (Design guide of Magnesium Elektron, 2012). This is not often necessary in castings where the section thickness is often oversize by design rather due to limiting stiffness. For this reason it is often possible to take full advantage of the lower density of magnesium in the cast form. Geometric Properties of alloy wheel are in Table 1.

## 1.10. Computer Modeling and Simulation of Alloy Wheel

Modeling and simulation represent catalysts capable of synthesizing formal theory and experimental results, breaking artificial barriers between these two main approaches to scientific discovery and engineering advances. Recently, computational simulation has become a third approach

# SIMULATION RESULT DETAILS

|                                     | With 6 Spokes Al alloy                                                                        | With 5 Spokes Al alloy                                                                          | With 4 Spokes Mg alloy                                                                           |
|-------------------------------------|-----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| MESHED MODELS                       | <br>fig. 1   | <br>fig. 8     | <br>fig. 15   |
| STRESS ANALYSIS                     | <br>fig. 2   | <br>fig. 9     | <br>fig. 16   |
| DISPLACEMENT ANALYSIS               | <br>fig. 3 | <br>fig. 10  | <br>fig. 17 |
| STRESS ANALYSIS FOR BREAKING TORQUE | <br>fig. 4 | <br>fig. 11 | <br>fig. 18 |

|                                           |                                                                                                  |                                                                                                    |                                                                                                     |
|-------------------------------------------|--------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| DISPLACEMENT ANALYSIS FOR BREAKING TORQUE |  <p>fig. 5</p>  |  <p>fig. 12</p>  |  <p>fig. 19</p>  |
| FATIGUE LIFE ANALYSIS                     |  <p>fig. 6</p>  |  <p>fig. 13</p>  |  <p>fig. 20</p>  |
| ISOMETRIC VIEWS OF MODELS                 |  <p>fig. 7</p> |  <p>fig. 14</p> |  <p>fig. 21</p> |

- along with theory and laboratory simulation - to studying and solving scientific and engineering problems. Computational simulation is based on the use of high-performance computers to model and simulate complex systems. In this approach, a computer equipped with problem-solving software tools may represent a virtual laboratory in which researchers can build a model for a given problem and run it under varying conditions. These increasingly complex computational methodologies require sophisticated models and numerical algorithms, and vice versa. This work applies these new computational methods for performing simulation on alloy wheel with different spokes.

In computer-aided design, geometric modeling is concerned with the computer compatible mathematical description of the geometry of an object. The mathematical description allows the model of the object to be displayed and manipulated on a graphics terminal through signals from the CPU of the CAD system. The software that provides geometric modeling capabilities must be designed for efficient use both by the computer and the human designer. To use geometric modeling, the designer constructs the graphical model of the object on the CRT screen of the ICG system by inputting three types of commands to the computer. The first type of command generates basic geometric elements such as points, lines, and circles. The second type command is used to accomplish scaling, rotation, or other transformations of these elements. The third type of command causes the various elements to be joined into the desired shape of the object being created on the ICG system. During this geometric process, the computer converts the commands into a mathematical model, stores it in the computer data files, and displays it as an image on the CRT screen. The model can subsequently be called from the data files for review, analysis, or alteration. The most advanced method of geometric modeling is solid modeling in three dimensions.

### 1.11. Modeling of alloy wheel using PRO-E

Top 10 reasons for choosing Pro/ENGINEER Wildfire:

- 1) More Powerful, Mature Functionality in an Affordable Entry-Level Package
- 2) More Complete Set of Tools—On a Single Native Architecture
- 3) Geometry Constrained from the Outset

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- 4) Auto build—Much More Than a 2D-to-3D Conversion Tool
- 5) Advanced Surfacing Tools
- 6) Large Assembly Management Tools
- 7) Design Quality Assurance Tools—Model CHECK
- 8) Powerful Connections to Third-Party CAD Data
- 9) Web Connectivity and Web-based Design Conferencing
- 10) Room to Expand into a Complete Product Development System.

## 1.12. Modeling Procedure

- Creating the Spoke of the wheel to draw a spoke profile, select a BLEND tool, where we define the attributes, Section, Direction and Depth.
- Creating Circular Pattern for Spoke Select the spoke, which is to have a circular pattern, Select the PATTERN tool from the Sketcher menu.
- Creating the HUB part for wheel Select the Extrude tool from the sketcher menu, then right click on mouse to get an internal sketch option, choose it. Select the plane on which the hub profile has to draw, and then create a HUB profile using circle option.
- Creating the Rim Part of wheel Select the plane, on which the Rim profile has to draw, then choose the Revolve option, by right clicking the mouse on window will get an internal sketch option, select it. Draw the Rim profile as per the dimensions required, then choose an axis to which the profile has to revolve, using the revolve dash board on the window screen. Then the required shape of the Rim will get.
- Creating the Ribs for Hub part Select the plane on which the rib profile has to draw, using the sketcher menu, draw the required shape of the rib, Ribs are used for stiffness of the wheel. Using the Extrude tool, specify the height and width of the rib.
- Creating the round edges at corners select the round tool from the menu bar. Select the edges that are required to smoothen, with different radii.
- Creating the air nipple Select the datum plane tool from the menu bar, choose the plane to which, the created datum plane should be.
- Define the placement for created datum plane. Select the Extrude tool from the sketcher menu, then right click on mouse to get an internal sketch option, choose it.
- Select the plane on which the profile of Air Nipple has to draw. Using the extrude dash board options; enter the required depth and thickness for the profile.

## 2. ANALYSIS

Designers and engineers primarily use structural simulation to determine the strength and stiffness of a product by reporting component stress and deformations. The type of structural analysis performs depends on the product being tested, the nature of the loads, and the expected failure mode. A short/stocky structure will most likely fail due to material failure (that is, the yield stress is exceeded). For the given below specification of the alloy wheel, the static analysis is performed using solid works to find the maximum safe stress and the corresponding payload. After geometric modeling of the alloy wheel with given specifications it is subjected to analysis. The Analysis involves the following discretization called meshing, boundary conditions and loading.

### 2.1. About analysis with Solid Works

Solid Works Simulation Xpress is design analysis software that is fully integrated in solid Works. SolidWorks Simulation Xpress simulates the testing of your part's prototype in its working environment. It can help you answer questions like: how safe, efficient, and economical is your design. Solid Works Simulation Xpress is used by students, designers, analysts, engineers, and other professionals to produce safe, efficient, and economical designs.

### 2.2. Fatigue Analysis

During design validation, a structure is exposed to both static strength tests and fatigue tests. However, once a structure is deployed, it spends the vast majority of its lifetime being subjected to smaller repeated forces that can cause cumulative damage over time. For this reason, testing the durability of a structure makes up a larger proportion of the tests that are run. Durability is one of the most important attributes that structures can possess. Fatigue testing measures durability and is defined as the repeated mechanical loading of a structure to determine failure points. It requires complex analysis using the field of fracture mechanics, which is the analysis of material flaws to discover those that are safe and those that are liable to propagate as cracks and cause failure.

Add an event as constant amplitude for a required number of cycles, with zero based condition. Then define S-N curve for the applied material, as log-log graph. The Stress-Life (S-N) or Total Fatigue Life method is widely used for HCF applications. During HCF testing, a material spends the majority of life in a state where the cracks are very small, the growth is controlled, and the structure integrity is retained (Beginner's Guide to SolidWorks 2013).

As noted earlier, the applied stress stays within the elastic range of the material. Total Life is determined by running multiple specimen tests at a number of different stresses. The objective is to identify the highest stress that produces a fatigue life beyond 10 million cycles. This stress is also known as the material's endurance limit.

### 2.3. Meshing

Meshing involves division of the entire of model into small pieces called elements. This is done by meshing. It is convenient to select the Standard mesh because of wheel structures, so that shape of the object will not alter.

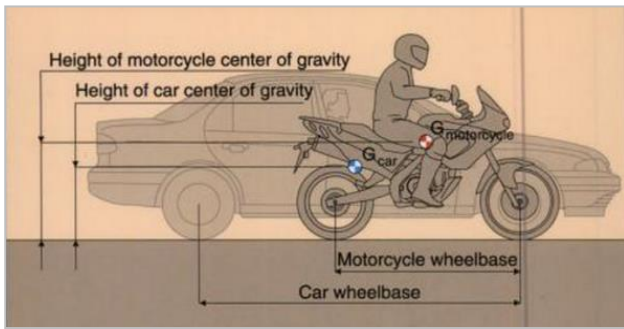


Figure 22  
Position of center of gravity (CG)



Figure 23  
Normal reaction on rear wheel

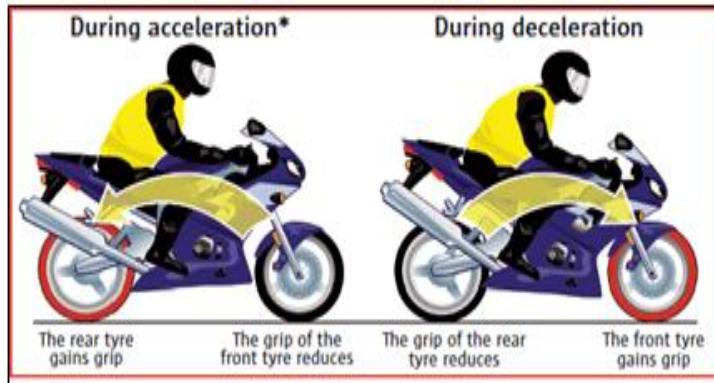


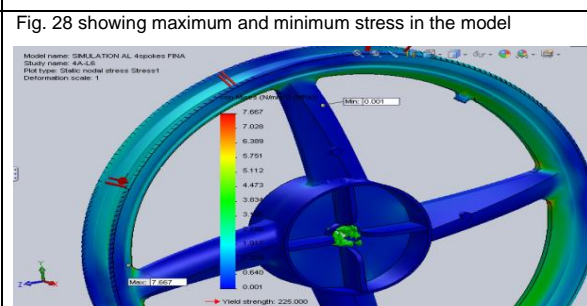
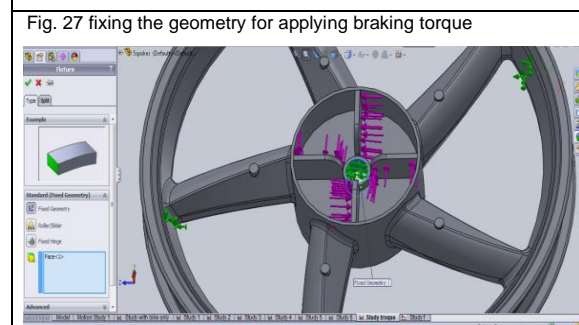
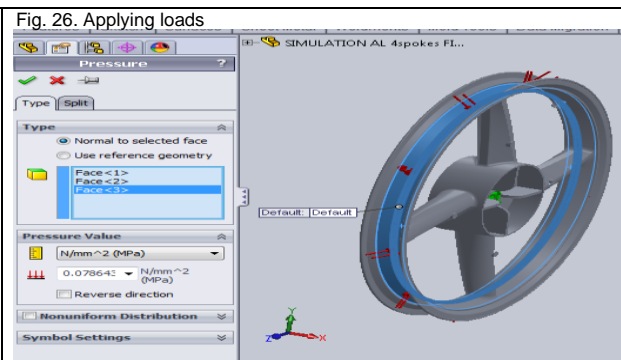
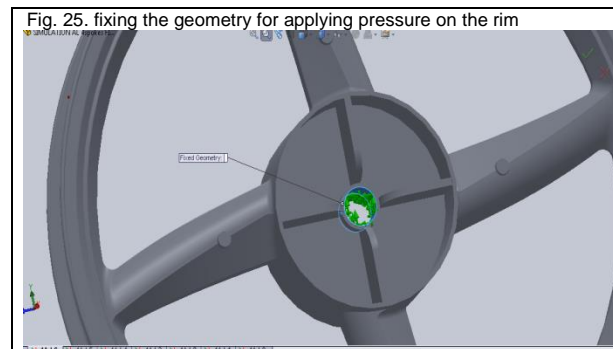
Figure 24  
Braking torque effecting wheels

## 2.4. Boundary Conditions

To ensure the accuracy and reliability of the analysis result, the structural and mechanical model of the rear wheel is established. Figure 1 shows the existing models figure 7, 14 and redesigned model (Figure 21). Net weight of the motorcycle is 163 kg and the maximum allowable Load 6. The tyre used is a common version with inner tube filled to gas pressure 0.28 MPa, uniformly distributed on the exterior ring surface of wheel. To ensure reliability of the analysis, the sum of motorcycle net weight and maximum allowable load was applied to the rear wheel alone. The sum was considered to be the maximum load, which was distributed on the rim surface.

By considering, the maximum load is equal to motorcycle

weight including rider and all loads. Type of model is Linear Elastic Isotropic. Tensile test results of S-RS P/M and RS P/M ZK60 (Zhenya Zhang et al. 2010) alloys at room temperature and the material properties of the given alloy wheel are given table 2 and 3.



**Table 4**  
Stress analysis values for 6,5 and 4-Spokes Al and Mg-alloy wheels

| S.NO | LOAD        | load (N) | Pressure On Rim (MPa) | Stress in 6 spoke Al alloy (MPa) | Stress in 6 spoke Mg alloy (MPa) | Stress in 5 spokes Al alloy in (MPa) | Stress in 5 spokes Mg alloy in (MPa) | Stress in 4 spokes Al alloy (MPa) | Stress in 4 spokes Mg alloy (MPa) |
|------|-------------|----------|-----------------------|----------------------------------|----------------------------------|--------------------------------------|--------------------------------------|-----------------------------------|-----------------------------------|
| 1    | VECHLE LOAD | 1119.321 | 0.023180549           | 2.17                             | 2.18                             | 2.35                                 | 2.355                                | 2.26                              | 2.267                             |
| 2    | with 1 Man  | 1565.676 | 0.032424326           | 3.03                             | 3.044                            | 3.285                                | 3.289                                | 3.161                             | 3.171                             |
| 3    | with 2 Men  | 2012.031 | 0.041668103           | 3.9                              | 3.916                            | 4.225                                | 4.227                                | 4.065                             | 4.075                             |
| 4    | with 3 Men  | 2458.386 | 0.05091188            | 4.76                             | 4.78                             | 5.162                                | 5.164                                | 4.963                             | 4.979                             |
| 5    | with 4 Men  | 2904.741 | 0.060155657           | 5.622                            | 5.644                            | 6.099                                | 6.102                                | 5.865                             | 5.882                             |
| 6    | with 5 Men  | 3351.096 | 0.069399434           | 6.49                             | 6.517                            | 7.036                                | 7.04                                 | 6.766                             | 6.787                             |
| 7    | with 6 Men  | 3797.451 | 0.078643211           | 7.35                             | 7.381                            | 7.973                                | 7.977                                | 7.667                             | 7.691                             |

**Table 5**  
Weight (N) reduction in the model

| No. of spokes | Mg      | Al      | % of weight saving |
|---------------|---------|---------|--------------------|
| 6 spokes      | 24.3911 | 40.1294 | 60.78              |
| 5 spokes      | 21.8042 | 35.8761 | 60.77              |
| 4 spokes      | 19.1728 | 31.608  | 60.66              |

**Table 6**  
Max. Von Mises Stress due to braking torque in the wheel (by considering drum braking)

|                           |                                        |
|---------------------------|----------------------------------------|
| in 6 spoke Al-alloy wheel | 251.526 > yield stress                 |
| in 4 spoke Al-alloy wheel | 250.148 > yield stress                 |
| in 4 spoke Mg-alloy wheel | 246.472 < yield stress (safe stresses) |

Mesh Information and simulation details are represented as in table

#### Applied Loads

- Load 0 = weight of Bike (143 vehicle +20extra kg)
- Load 1 = (163+65) kg
- Load 2 = (163+65X2) kg
- Load 3 = (163+65X3) kg
- Load 4 = (163+65X4) kg
- Load 5 = (163+65X5) kg
- Load 6 = (163+65X6) kg

#### Analysis for strength needed

Mass of Bike, Dead Weight of Bike =143kg

Other Loads = 20 Kg

Total Gross Weight =143 + 20 = 163 Kg  
= 163X 9.81 N

Tires and Suspension system reduced by 30% of Loads

$W_{net} = 163 \times 9.81 \times 0.7 \text{ N} = 1119.32\text{N}$

Reaction Forces On Bike= $N_r = 1119.32\text{N}$

Number of Wheels: 2

But by considering total Reaction Force on only one wheel  $F_T = 1119.32\text{N}$

Rim surface area which is having 6 spokes:  $A_6 = 48299.69 \text{ mm}^2$  (this can be obtained from selecting faces on rim by using measuring tool in solid works)

Stress on the each Rim =  $\frac{N}{A} = 0.02321 \text{ N/mm}^2$

So pressure on the each rim for load 0 = 0.02321 N/mm<sup>2</sup>

It is similarly for different Loads Stress on Each Rim with Loads

Pressure by Load 1 = 0.0324 N/mm<sup>2</sup>

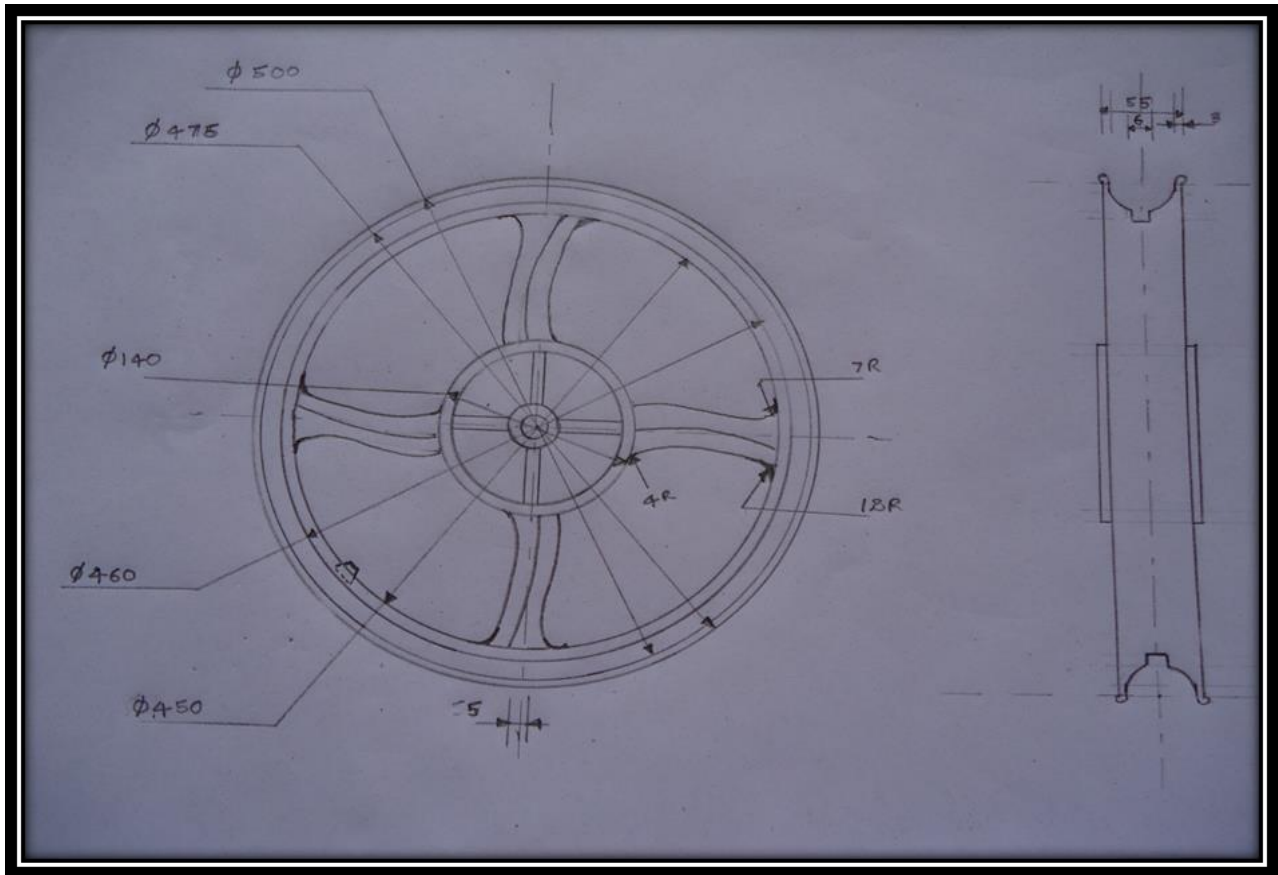
Pressure by Load 2 = 0.0417 N/mm<sup>2</sup>

Pressure by Load 3 = 0.0509 N/mm<sup>2</sup>

Pressure by Load 4 = 0.0601 N/mm<sup>2</sup>

Pressure by Load 5 = 0.0694 N/mm<sup>2</sup>

Pressure by Load 6 = 0.0786 N/mm<sup>2</sup>



**Figure 29**  
Drawing of new model alloy wheel

### Applying Pressures

Apply 0.011945MPa pressure simulations normal to the faces as shown in the figure  
Again it is similarly for rims with spokes 5 & 4. The simulation results are as shown in figures.

### Applying Braking Torque

In general Acceleration of the street motorcycle:  $a = (v_f - v_i) / t$

$v_f$ - final velocity= max of 60miles in 3.5sec

$v_i$ - initial velocity = 0 miles,

$\Rightarrow a$  - acceleration =  $7.6636m/s^2$

Brake force is required to estimate the load on the wheel hub.

Now Total force acting on the vehicle:

Mass of the vehicle including rider and other five more persons  $M = 163 + 65 \times 6$

$F_{total} = M \times a = 4237.9 \text{ N}$

### Torque on the hub

$T = F_r \times R$  in N.m (here  $F_r$  is the force on the each wheel=  $0.5F_{total}$  & is  $R$  radius of the rim = 0.25m )

$T = 2119 \times 0.25 = 529 \text{ N.m}$

## 3. RESULTS AND DISCUSSIONS

Stress analysis values for 6, 5 and 4-Spokes Al and Mg-alloy wheels are in Table 4 .The Stresses induced in the 4-Spokes Mg Alloy wheel 7.686 MPa is less as compared with the Stresses induced in the 5-Spokes Al alloy (AM60A), and also nearer to Al-alloys with 6 spokes. So in the 4 spoke model can substitute to the 6 or 5 spoke wheels safely.

## 4. CONCLUSIONS

1. The maximum stress area was located at Spoke-Rim contact.

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2. Stresses induced in 4-Spokes Alloy wheel are less as compared with Al-Alloy of the 5 and 6 Spokes.
3. The weights of the Mg alloy with 4-Spokes wheel is less as compared with Al-Alloy of the 6, 5 and 4 Spokes.
4. Fatigue life cycle is estimated.
5. Fatigue life cycle for the Mg-alloy is more as compared with all Al-alloys materials.
6. Induced Stress due to braking torque in the 4 Mg-Spoke wheel are lesser than the remaining wheels.
7. Material reduction can be done by reducing number of Spokes. The objective was to reduce the weight of the alloy wheel has been achieved.

The current design is 60% lighter than the original design (Table 5 & 6).

The objective was to reduce the weight of the alloy wheel has been achieved. The current design is 60% lighter than the original design. In this work the overall dimensions are controlled by reducing number of spokes to the alloy wheel with same functioning stability and less weight. The stress and displacements in 4 spoke alloy wheel are lesser than six and five spokes alloy wheels. And also having higher FOS in the four spoke model design.

## FUTURE ISSUES

1. Further to do optimization of material thickness to reduce the material consumption.
2. Further to improve life of component by using advanced fatigue strain life approach.
3. For designing hub less wheels.

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